A Novel Deorientation Method for PolSAR Data Processing

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Abstract

In PolSAR data processing, deorientation operation is often necessary. The existing deorientation method uniformly deorients all the sub-scatterers of a resolution cell with one orientation angle. For high entropy situation, the sub-scatterers have diverse OAs, and the effect of the existing method is unsatisfactory. A novel deorientation method is proposed to well treat the high entropy situation. Cloude's eigen-decomposition to the coherency matrix is first carried out. The three eigenvectors are then separately deoriented with their own orientation angles. Experiments demonstrate that the proposed method is suitable for extraction of urban regions, especially for extraction of oriented urban regions.

1   Introduction

Deorientation operation plays an important role in fully polarimetric synthetic aperture radar (PolSAR) data processing. For currently widely used deorientation method (the existing method) proposed in [1, 2], the coherency matrix is rotated some angle about the radar line of sight (LOS). Only one "mixed" orientation angle (OA) is used. However, there are numerous scatterers in one resolution cell, and there is a real chance that they have different OAs. In oriented urban regions which are not aligned in the track direction, there may be roofs with azimuth slopes, oriented walls, and oriented dihedrals in one cell [3], for instance. They all have different OAs. Only one OA cannot effectively account for this situation. A novel deorientation method is thus proposed with OA variations (three OAs) taken into consideration, and the objective of which is to fit the scatterers with different OAs in one resolution cell.

2   Existing Deorientation Method

2.1   Existing Method

The existing deorientation method [1, 2] which has gained wide applications can be represented as

$$T_c = R(\theta)TR^{-1}(\theta), R(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \quad (1)$$

where T and T_c denote the coherency matrix and the deoriented coherency matrix with the existing method respectively, and $R(\theta)$ is the OA rotation matrix. The OA θ can be derived by the two methods proposed in [1, 2]. The OA is derived as the phase difference between the co-polarization terms based on circular polarization covariance matrix in [1], and is equivalently derived by minimizing the cross-polarization power in [2]. The derived OA is

$$\theta = \frac{1}{4}\text{atan}\left[2\text{Re}(T_{23}) \Big/ (T_{22}-T_{33}) \right]. \quad (2)$$

where $\text{Re}(\cdot)$ denotes the real part of a complex number.

2.2   Another Interpretation of the Existing Method

Here, the existing method is reconsidered and interpreted in a different way. Via Cloude's eigen-decomposition [4], the coherency matrix is decomposed as

$$T = \sum_{i=1}^{3} \lambda_i k_i k_i^H = \sum_{i=1}^{3} T_i \quad (3)$$

where λ_i, k_i, and T_i are the eigenvalue, eigenvector, and single target, respectively, and $\lambda_1 \geq \lambda_2 \geq \lambda_3$ is assumed. This provides a statistical interpretation of the target, i.e. a three-symbol Bernoulli process is adopted [4]. Thus, the existing method of (1) can be rewritten as

$$T_c = R(\theta)\left(\sum_{i=1}^{3} T_i\right)R^{-1}(\theta) = \sum_{i=1}^{3} R(\theta)T_i R^{-1}(\theta) \quad (4)$$

The three single targets, T_1, T_2, and T_3, are deoriented about the radar LOS with one same OA. Actually as mentioned previously, the sub-scatterers in one cell may likely have different OAs, and that is to say that T_1, T_2, and T_3 have their own OAs. Motivated by this point, a novel deorientation method is raised in this paper, i.e. T_1, T_2, and T_3 are separately deoriented with their own OAs, respectively.

3 Proposed Deorientation Method

3.1 Proposed Method

The proposed method reconstruct the sub-scatterers of a resolution cell, and the sub-scatterers are projected to three orthogonal single targets via Cloude-Pottier eigen-decomposition of the coherency matrix. Then the three single targets are separately deoriented, i.e.

$$T_p = \sum_{i=1}^{3} R(\theta_i) T_i R^{-1}(\theta_i) \quad (5)$$

where T_p is the deoriented coherency matrix with the proposed deorientation method, T_i is the single target obtained with (2), and θ_i is the OA of each single target T_i.

One noteworthy feature of the proposed method is that the real part of T_{p13} element is zero, which is consistent with Huynen's deorientation theory that Huynen parameter H (real part of T_{p13} element) becomes zero after deorientation [5]. But for the existing method, it is not the case, the real part of T_{c23} element is zero.

The eigenvector k_i is here modelled by Kennaugh-Huynen's co-diagonalization of scattering matrix [6, 7], and its OA θ_i can be afterwards derived. The corresponding scattering matrix S_i of eigenvector k_i can thus be modelled as

$$S_i = R_S(\theta_i) R_S(\tau_i) S_{di} R_S(\tau_i) R_S(-\theta_i) \quad (6)$$

where S_{di} is the diagonal matrix whose diagonal elements are the complex con-eigenvalues of x_{i1} and x_{i2} respectively, and θ_i and τ_i are the OA and helix angle, respectively. The unitary transformation matrices are respectively

$$R_S(\theta_i) = \begin{bmatrix} \cos\theta_i & -\sin\theta_i \\ \sin\theta_i & \cos\theta_i \end{bmatrix} \quad (7)$$

and

$$R_S(\tau_i) = \begin{bmatrix} \cos\tau_i & -j\sin\tau_i \\ -j\sin\tau_i & \cos\tau_i \end{bmatrix}. \quad (8)$$

The eigenvector k_i can be obtained by expanding and rewriting the scattering matrix of (6) in Pauli basis as

$$k_i = \begin{bmatrix} \frac{x_{i1}+x_{i2}}{2}\cos 2\tau_i \\ \frac{x_{i1}-x_{i2}}{2}\cos 2\theta_i + j\frac{x_{i1}+x_{i2}}{2}\sin 2\tau_i \sin 2\theta_i \\ \frac{x_{i1}-x_{i2}}{2}\sin 2\theta_i - j\frac{x_{i1}+x_{i2}}{2}\sin 2\tau_i \cos 2\theta_i \end{bmatrix} \quad (9)$$

$$= \begin{bmatrix} k_i(1) & k_i(2) & k_i(3) \end{bmatrix}^T.$$

The OA θ_i can be derived from (9) as

$$\theta_i = \frac{1}{2}\text{atan}\left[\frac{\text{Re}\left[k_i(3)/k_i(1)\right]}{\text{Re}\left[k_i(2)/k_i(1)\right]}\right]. \quad (10)$$

The range of θ_i is $[-45°, 45°]$. The above derived OA θ_i of (10) is equivalent to that derived in [8].

3.2 Physical Interpretation

The main idea of the proposed method is to rotate the three single targets about the LOS separately with different OAs instead of rotating them together with only one OA. We have numerous ways of decomposing one distributed target into three single targets, and Cloude's eigen-decomposition is chosen here. As an analytical tool, the Cloude's eigen-decomposition provides a concise and unique decomposition of the coherency matrix, and enables us to interpret the target in a higher dimension. Via eigen-decomposition, the coherency matrix is decomposed into three statistical single targets (three eigenvectors), and then the mean OAs of three single targets are all compensated. This results in that the proposed method is suitable for urban regions extraction, especially for characterisation of oriented urban regions. In oriented urban regions, there may be roofs with azimuth slopes, oriented walls, and oriented dihedrals and so on in one cell. These sub-scatterers are contained in the three single targets T_i, and the proposed method just separately rotates the three single targets with their own OAs.

4 Comparisons Between the Two Methods

4.1 Mathematical Comparison

From the mathematical point of view, the only difference between (4) and (5) is that the existing method uniformly rotates the three eigenvectors (the three targets) with a same OA θ about the LOS while the proposed method separately and adaptively rotates the three eigenvectors with their own OAs θ_1, θ_2, and θ_3 about the LOS. Then the proposed method can be viewed as a natural extension of the existing method. The three deoriented eigenvectors by the existing method is still orthogonal, but not the case by the proposed method. The two deoriented coherency matrix, i.e. T_c and T_p, are both positive semi-definite and physical meaningful.

4.2 Experimental Results

Here, several experiments are carried out to demonstrate the different performances of the two methods. The RADARSAT-2 PolSAR data of San Francisco area are used [9]. The data are in single-look complex (SLC) format. For speckle reduction and getting the coherency

matrix format data, a 7×7 refined Lee filter is implemented on the data. Only a part of the scene is utilized.

4.2.1 Comparisons Between the OAs

The OA θ of (2) used in the existing method and the OA θ_1 of (10) of the dominant eigenvector used in the propposed method are demonstrated and compared, and are shown in **Figure 1**.
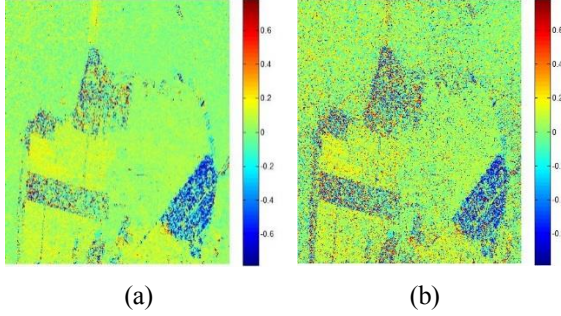

(a)   (b)

Figure 1: a) OA of the existing method; (2) OA θ_1 of the proposed method

Four 100×100 typical patches are selected for further comparison. As shown in **Figure 2** of Google Earth optical image, the selected patch 1-4 are ocean region, urban region, oriented urban region, and park region, respectively.

Figure 2: Google Earth image of selected patches.

The statistical distributions of the OA θ used in the existing method and the OA θ_1 used in the propposed method for the four patches are shown in **Figure 3**.
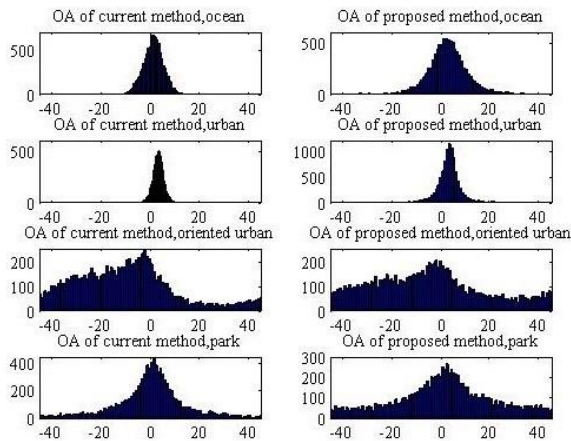

Figure 3: Histgrams of the OAs of the four patches.

From **Figure 1** and **Figure 3**, we can see that θ and θ_1 are consistent in general, but the OA θ_1 of the dominant eigenvector is noisier as also mentioned in [10]. **Figure 1** shows that the OAs reasonably have large minus values in oriented urban region, such as patch 3.

4.2.2 Impacts of the Two Methods on the Model-based Decompsition

The two deorientation methods have different imapcts on the PolSAR model-based polarimetric decomposition, as will be shown in the folowing. As the deorientation methods are the emphasis, original Freeman-Durden three-component decomposition (FDD) without any modifications [12] is just selected here. The FDD is carried out based on the deoriented T_c and T_p.

First, the negative power problem is tested. It is well known that the negative power phenomenon of FDD voliates the physical reality. Based on original FDD, 14.86% pixels have negative power. That numbers for FDD with the existing deorientation method and FDD with the proposed deorientation method are 8.74% and 7.77%, respectively. Thus the proposed method is more effective in alleviating this physical voliating phenomenon.

Second, the impacts of the two methods on the decomposed scattering mechanisms and power proportions of the three components are studied. The color-coded decomopistion results of FDD, FDD with the existing method, and FDD with the proposed method are shown in **Figure 4**, respectively. Blue color stands for surface scattering, red color stands for double-bounce scattering, and green color stands for volume scattering.
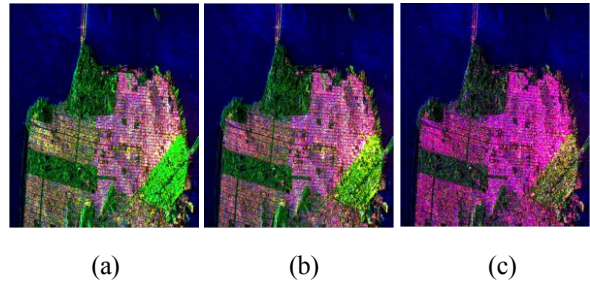

(a)   (b)   (c)

Figure 4: Decomposition results of a) FDD, b) FDD with the existing method, and c) FDD with the proposed method.

The average power proportions of the four patches are demonstrated in **Table 1-4**.

Method	P_s	P_d	P_v
FDD	92.29%	2.58%	5.14%

Method	P_s	P_d	P_v
FDD with the curret method	92.46%	2.72%	4.82%
FDD with the proposed method	94.17%	4.43%	1.4%

Table 1: Average power proportions of patch 1 ocean region.

Method	P_s	P_d	P_v
FDD	29.32%	51.12%	19.56%
FDD with the curret method	31.16%	52.78%	16.06%
FDD with the proposed method	33.78%	54.95%	11.27%

Table 2: Average power proportions of patch 2 urban region.

Method	P_s	P_d	P_v
FDD	-7.78%	3.47%	104.3%
FDD with the curret method	0	27.79%	72.21%
FDD with the proposed method	16.11%	38.96%	44.93%

Table 3: Average power proportions of patch 3 oriented urban region.

Method	P_s	P_d	P_v
FDD	19.49%	8.07%	72.44%
FDD with the curret method	21.05%	16.39%	62.56%
FDD with the proposed method	34.72%	26.70%	38.58%

Table 4: Average power proportions of patch 4 park region.

For **Figure 4**, the red colors in urban regions are strenghened by the proposed deorientation method, especially in oriented urban regions, such as patch 3. By the existing method, the patch 3 oriented urban region is not discriminated as double-bounce scattering dominant region, but as volume scattering dominant region. By the proposed method, this phenomenon is improved, and the green colors in patch 3 partially turn to red or yellow. The power proportions in **Table 2-3** support the color change. Thus from the target classification point of view, the proposed method is more suitable for urban regions extraction, especially for oriented urban regions extraction. The green colors in park region, such as patch 4, are weakened by the proposed method, but the park region can still be correctly discriminated as volume scattering dominant region. The power proportions in **Table 4** support the statement that the proposed method gets lower average volume scattering power than the curret method.

5 Discussion

The proposed deorientation method is designed to better treat the high entropy regions. The high entropy regions usually include the oriented urban regions and forest regions. For oriented urban regions, the proposed method has more reasonable and superior performance than the existing method as previously demonstrated. For forest regions, the proposed method gets lower average volume scattering power than the existing method does. Although the forest regions can be correctly discriminated as volume scattering dominant regions by the proposed method, such as patch 4, one question may still be raised that does the proposed method underesti-

mate the volume scattering power in forest regions? First, the volume scattering is modelled by the backscattering from a cloud of dipoles, and the OAs of the dipoles obey some probability distribution. The commonly applied uniform distribution and half cosine distribution are the centered at zero value, and this is consistent with the OA distributions of patch 4 in Figure 3. Second, the eigenvector of dipole scattering mechanism corresponds to the volume scattering part. Mean OA or the center OA of the OA distribution of the eigenvector is compensated for each eigenvector by the proposed method. As mentioned before, the OAs of forest regions usually center at zero generally, therefore, the deorientation effect on the eigenvector that corresponds to the volume scattering is very small. Thus the proposed method does not underestimate the volume scattering power for this general case. For the few targets whose mean OAs are not centered at zero, the mean OAs of the eigenvectors of dipole scattering mechanism will be rotated, and the volume scattering power from the canopy for this case may be underestimated, which may be the foreseen limitation of proposed method. However, it is difficult to expect that one method can fit all kinds of targets.

6 Conclusion

Updated from the existing deorientation method proposed by Lee *et al.* and An *et al.* which utilizes one average OA to uniformly rotate the coherency matrix, a novel deorientation method whose objective is to fit the scatterers with different OAs in one resolution cell is proposed. The proposed deorientation method separately rotates the three single targets with their own OAs obtained by the eigen-decomposion of the coherency matrix. One feature of the proposed method is that it is consistent with Huynen's deorientation theory, i.e. the real part of the T_{13} becomes zero after deorientation, but not the case for the existing method. Experimental results demonstrate that the proposed method is suitable for urban regions extraction, expecially for oriented urban regions extraction.

References

[1] J. S. Lee, D. L. Schuler, and T. L. Ainsworth, "Polarimetric SAR data compensation for terrain azimuth slope variation," IEEE Trans. Geosci. Remote Sens., vol. 38, no. 5, pp. 2153-2163, Sep. 2000.

[2] W. T. An, Y. Cui, and J. Yang, "Three-component model-based decomposition for polarimetric SAR data," IEEE Trans. Geosci. Remote Sens., vol. 48, no. 6, pp. 2732-2739, Jun. 2010.

[3] H. Kimura, "Radar polarization orientation shifts in built-up areas," IEEE Geosci. Remote Sens. Lett., vol. 5, no. 2, pp. 217-221, Apr. 2008.

[4] S. R. Cloude and E. Pottier, "A review of target decomposition theorems in radar polarimetry," IEEE Trans. Geosci. Remote Sens., vol. 34, no. 2, pp. 498-518, Mar. 1996.

[5] J. R. Huynen, "Phenomenological theory of radar targets," Ph.D. Dissertation, Tech. Univ. Delft, Delft, The Netherland, 1970.

[6] J. R. Huynen, "Measurement of the target scattering matrix," Proc. IEEE, vol. 53, no. 8, pp. 936-946, Aug. 1965.

[7] R. Touzi, "Target scattering decomposition in terms of roll-invariant target parameters," IEEE Trans. Geosci. Remote Sens., vol. 45, no. 1, pp. 73-84, Jan. 2007.

[8] Lionel Bombrun et al, "Roll invariant target detection based on POLSAR clutter models," Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, USA, pages 2511–2514, 2010.

[9] http://gs.mdacorporation.com/SatelliteData/Radarsat2/SampleDataset.aspx

[10] S. R. Cloude, "Decomposition theorems" in Polarisation Applications in Remote Sensing. Oxford, U.K: Oxford Univ. Press, 2010, pp. 183-184.